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Schmidt, Gunnar; Dooley, Laurence S. and Buchwald, Wolf-Peter (1994). A PALplus-Compatible HDTV Encoder System. IEEE Transactions on Consumer Electronics, 40(3) pp. 207–215.

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A PALPLUS COMPATIBLE HDTV ENCODER SYSTEM

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ABSTRACT

This paper presents a new implementation for realising PALplus signals from High-Definition Television (HDTV) transmissions. A proposed encoder design is introduced, which decomposes the HDTV input into two separate channels, the first of which subsamples the input signal to produce the standard resolution TV signal, and the second derives a digitally compressed residual component. The problems of non-uniform line structure due to the decimation of an interlaced signal are addressed, as are the visible distortions caused by aliasing and cross-talk effects, with appropriate solutions presented. Finally the important issues of colour enhancement and the composition of the compatible signal are briefly discussed.

1. Introduction

PALplus is a recent European development aimed at overcoming the system dependent limitations inherent in normal PAL TV systems. It was developed primarily as a terrestrial counterpart to the D2MAC (Multiplexed Analog Components) standard, which is used in satellite communications. The normal 4:3 aspect ratio for PAL signals has been widened to 16:9, so it has the same format as D2MAC, but without the corresponding loss of compatibility with standard TV receivers [1]. It also means however, that PALplus does not provide any overall improvement in picture resolution, in comparison with HD-MAC (High Definition MAC), the D2MAC compatible HDTV broadcasting proposal.

The failure of MAC to be universally accepted as the future TV-standard has once again focussed attention upon high definition transmission systems, with the main areas of activity being predominantly concerned with seeking replete digital solutions. This paper deals with the equally important issue of compatibility, in particular between PALplus and HDTV signals. In contrast to earlier research [2][3][4][5] into

HDTV compatibility, the solution presented in this paper requires no additional channel capacity for transmission. Using a PALplus signal as the compatible reference, instead of a standard PAL signal implies a consistent 16:9 aspect ratio format, together with the added benefits of less cross-colour and cross-luminance distortion. It is the combination of the PALplus coded signal together with a high resolution, digitally compressed component, which is derived from efficient data compression techniques, that affords the opportunity of transmitting an HDTV signal in a compatible manner.

Fig. 1 shows the complete block diagram of the proposed encoder. The input HDTV signal is decomposed into two main components. Firstly, the down-conversion (decimation) section, which generates the standard resolution TV element to be subsequently PALplus coded to form the compatible signal. The second component is a digital augmentation or residual signal, which undergoes further digital compression before being integrated together with the analogue PALplus signal to form the composite HDTV signal.

This paper will concentrate upon the two processing blocks, decimation and residual processing. These will be fully elucidated in section two, following a brief overview of the characteristics of the PALplus system. In the decimator section, the effect of subsampling an interlaced signal is considered and the necessity for motion adaptive prefiltering discussed. The use of Quadrature Mirror Filter (QMF) techniques, in order to eliminate aliased artefacts in the reconstructed signal is also explored. As for the residual processing module, the performance of diagonal filtering methods will be analysed as the initial stage in deriving a compressed augmentation signal.

2. System parameters

2.1. The PALplus signal

In 1989, a European initiative commenced to try and improve the viewing experience of the standard colour PAL TV system. The resulting proposal, called PALplus, embraces a number of significant enhancements, including a wider 16:9 picture format, which is better

The authors wish to acknowledge the funding received under the ARC collaboration from the British Council and the DAAD (Grant No 443)

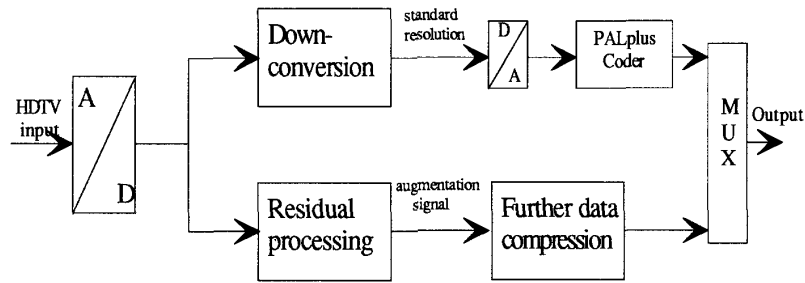


Figure 1: Block diagram of the proposed encoder

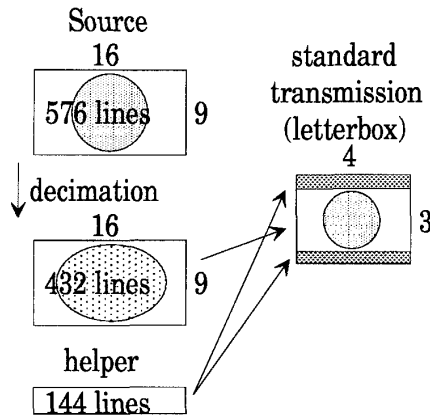


Figure 2: Example of a PAL compatible 16:9 transmission using the "Letterbox" format

suited to the human field of vision, together with a decrease in the cross distortions which afflict ordinary PAL pictures [1]. The other major aim of PALplus is that it should be fully compatible with the standard PAL system.

The issue of compatibility requires that PALplus has to support two different picture geometries, namely 16:9 and 4:3. To avoid visual distortion in standard TV receivers, the coder performs a vertical decimation from 576 active lines down to 432, so providing the correct aspect ratio on all 4:3 tubes, but with black bars appearing at the top and bottom of the screen, in the well known "Letterbox" format, as witnessed in Fig. 2. The additional vertical information necessary for reconstruction in the PALplus decoder, is referred to as the "vertical helper", and is transmitted in the 144 lines which comprise the unused black bars. To ensure that this information is not visible, it is modulated with the colour sub-carrier and attenuated in amplitude. A treatise upon this vertical band-splitting process is given in [6] and [7].

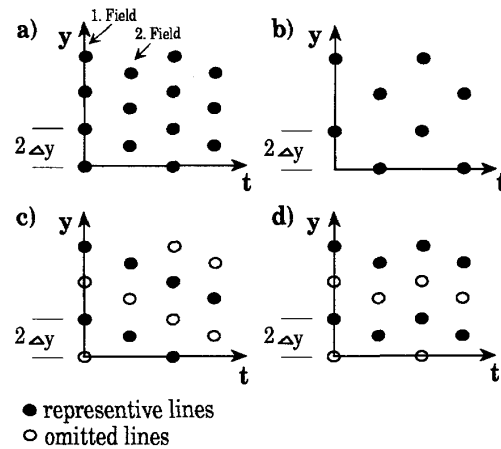


Figure 3: vertical/temporal sampling lattice of a) the input HDTV signal. b) the standard signal. c) the vertically decimated signal without respect to the field. d) as in c) but with the field reset.

To reduce the effect of both cross luminance and cross colour distortion and thus provide maximum luminance resolution, changes to the PAL coder and decoder have to be made, but without compromising the picture quality in standard TV receivers. The requisite signal processing in the PALplus coder and decoder is based on the "Colour plus" technique, details of which are delineated in [8].

2.2. The Down-conversion process

The European HDTV proposed standard is defined as; 1250 lines per frame, 50 fields per second and a 2:1 interlace. Compared with standard TV parameters, it possesses twice the horizontal and vertical resolution, which means that in order to subsample, each dimension has to be decimated by a factor of two.

In contrast to decimation in the horizontal plane, which is straightforward, down-sampling in the vertical plane raises a number of problems because of the

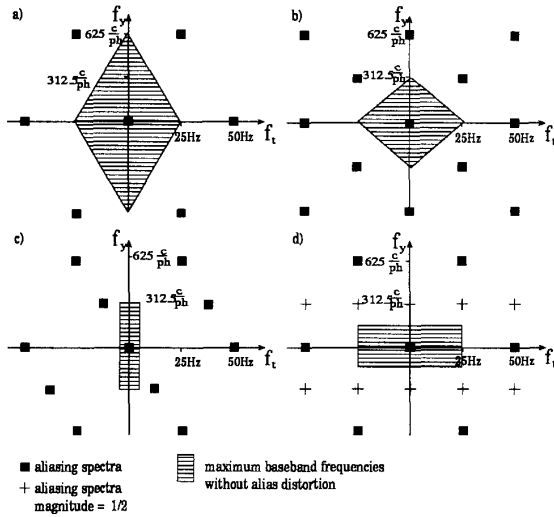


Figure 4: Corresponding spectra for Fig. 3

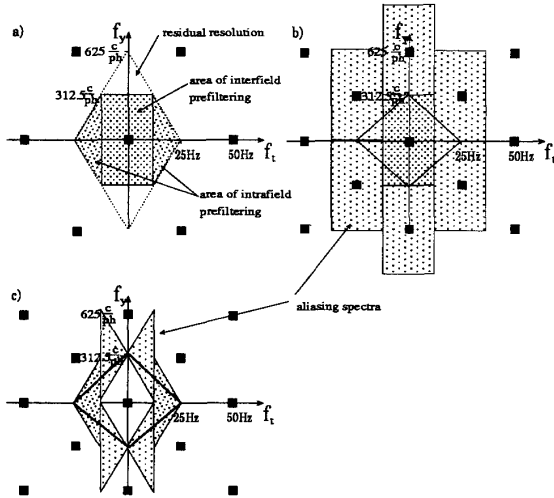


Figure 5: Spectrum of a) the motion adaptive filtered HDTV input. b) the subsampled "little-or-no" motion frequency region. c) the subsampled high motion frequency region.

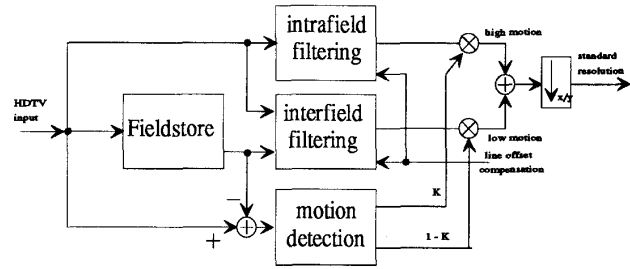


Figure 6: Block diagram of the motion adaptive down-converter used for this application

interlaced nature of the HDTV signal. Fig. 3a shows the vertical/time sampling lattice of such an input signal, while Fig. 3b evinces the equivalent standard resolution. Fig. 4 illustrates the respective spectra corresponding to the line positions given in Fig. 3 [9]. The line positions of the second field in the compatible image are clearly not a subset of those of the input. If this anomaly, caused by the decimation process is ignored, a non-uniform line structure will result as shown in Figs. 3c and d. This leads to additional aliased components being generated (see Figs 4c and 4d), which reduces the resolution to only a quarter, instead of half the input signal.

To obviate this non-uniform line structure, the two fields have to be processed separately. Two distinct prefilters, derived from the same prototype function, are designed to have an identical amplitude response, but different group delays. Switching synchronously with each field between the two filter coefficient sets, will interpolate the lines in every second field to their correct position. Fig. 7a illustrates the loss of resolution which occurs during subsampling without compensating for the line offset. The zone-plate picture represents the full resolution of the HDTV input signal shown in Fig. 4a. After subsampling by two, only a quarter actually remains free from aliasing (Fig. 4d). Fig. 7b shows the same input signal, but now with line offset compensation. The prefilters used in this example are derived from the impulse response given by:

$$h(n) = \frac{\sin(\pi * n - 3 + \alpha)}{\pi * n - 3 + \alpha} \quad n = 0 \dots 6 \quad (1)$$

which is an all-pass response, so there is no amplitude distortion. The value of α is respectively chosen as -0.25 and 0.25 for each field, so that the difference in the group delay compensates for the line offset.

When using intrafield filtering, the phase relationship between the two consecutive fields within a frame is not taken into account, so that frequencies greater than half the Nyquist frequency (312.5 c/ph) of the in-

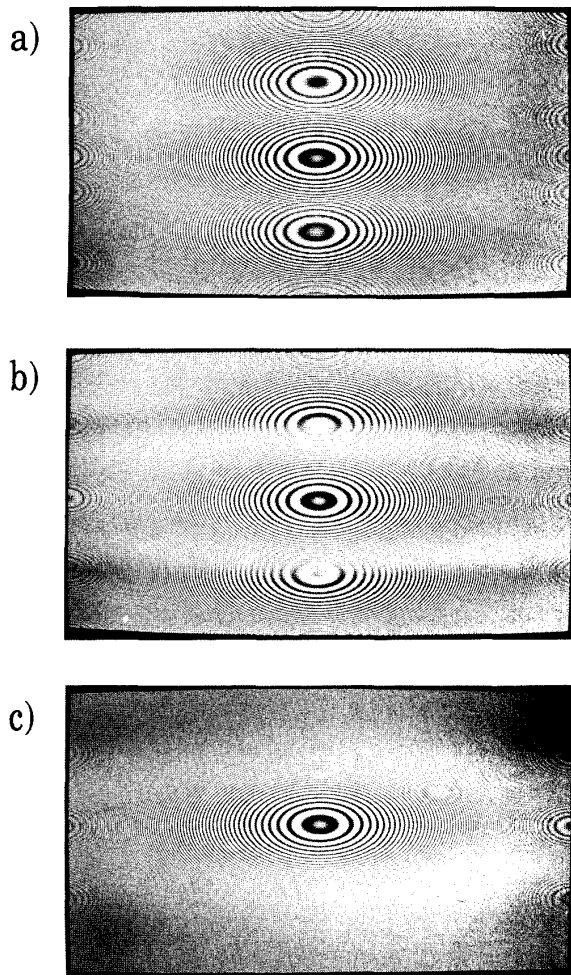


Figure 7: Zone-plate for demonstrating a) subsampling without prefiltering b) subsampling with line offset compensation c) interfield prefiltering with line offset compensation

put signal, are not suppressed and are clearly visible as aliased components. To prevent this unacceptable distortion, an interfield prefilter has to be used. Fig. 7c shows the effect of using such a filter pair. This approach achieves for the down-converted signal, the maximum vertical resolution without any aliasing artefacts, however a feature of interfield filtering, is that it introduces motion blur in moving (non-stationary) scenes.

To combine the advantages of the two prefiltering techniques, that is no motion artefacts in intrafield and maximum vertical resolution in interfield processing, a motion adaptive algorithm is employed in the design. For the case where little-or-no motion is detected, interfield prefiltering is used, whereas if high motion is detected, intrafield processing is performed. Fig. 5 graphically explains the situation. The HDTV input spectrum in Fig. 4a is processed exactly as described above. If it is assumed that an ideal motion detection is present at a temporal frequency of 12.5Hz , the resultant spectrum will be as shown in Fig. 5a, with the subsampled versions of the spectra for little-or-no motion and high motion shown in Fig. 5b and 5c respectively. Neither of these spectra fit entirely into the aliasing-free frequency region of standard TV receivers, so in certain instances aliased distortion will be visible. In reconstituting the full resolution picture however, these artefacts are not important, since there is no frequency overlap.

The decisive information required to select between the two processing methods, is obtained from a simple motion detector, based upon subtracting the corresponding pixel values from consecutive fields. Fig. 6 provides an insight into the complete down-conversion process.

2.3. Residual processing

Examination of the typical HDTV spectrum in Fig. 8a, reveals that the bandwidth requirement for transmission is at least four times that of the standard TV signal. This means that in the proposed implementation discussed above, the augmentation signal would be responsible for the remaining 75% of picture resolution. To reduce this unrealistic value, efficient data reduction techniques are employed. Two-dimensional diagonal filtering is initially performed to suppress all oblique frequencies in the spatial plane. Subjectively, the loss of such information is acceptable, since the probability of diagonal components occurring is generally much less than for either horizontal or vertical frequencies. The spectral effect of diagonal filtering is illustrated in Fig. 8. It can be seen that the input signal bandwidth is halved without compromising either horizontal or vertical resolution. The standard resolu-

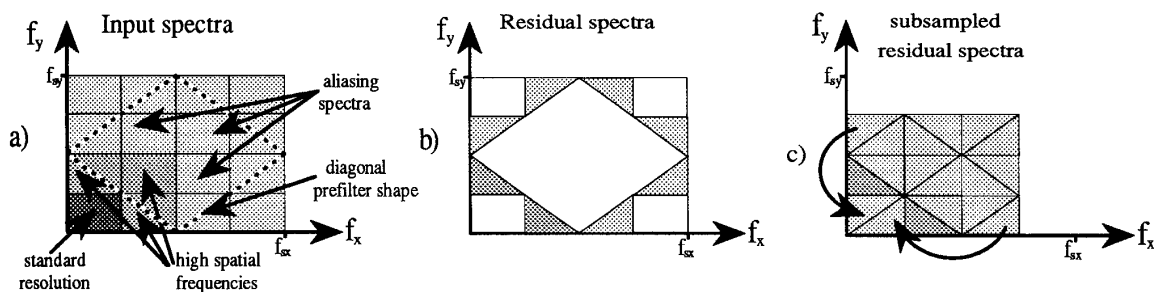


Figure 8: a) typical spectrum of an HDTV source; b) diagonally filtered residual spectrum (without the standard component); c) decimated residual spectrum

tion signal is obtained, with the residual spectrum consisting of only the wedge-shaped high frequency components shown in Fig. 8b. Following decimation by a factor of two, these spectral wedges fold back into the same frequency range as the standard signal, so the requisite bandwidth for the augmentation signal becomes equivalent to that of the normal resolution signal (see Fig. 8c).

The non-ideal characteristics of the prefilters, together with the decimation process in both paths of the proposed encoder in Fig. 1, lead to two different forms of aliased picture distortion. The first results from the band-splitting, highpass-lowpass filter combination, which precedes the subsampling process. The finite transition bandwidth of the two complementary filters means that aliased components, denoted by the horizontal and vertical criss-cross pattern in Fig. 9 are introduced, and will encroach upon the normal resolution signal, as well as the residual spectrum. Such aliasing is clearly visible in standard resolution pictures, so the design of the band-splitting filters has to balance the subjective picture quality with filter complexity, that is the order of the filters. Under a specific set of design conditions, this particular distortion can be eradicated from the reconstituted signal at the receiver, by using a QMF approximation [10]. The QMF filter family exhibit the unique perfect-reconstruction property, with the reconstituted signal being free from aliasing, as well as amplitude and phase distortion, which is a very propitious attribute in this particular application.

The second major source of aliasing error is found only in the residual path and is due to the non-ideal response of the diagonal filter. When the high resolution horizontal and vertical wedges are folded back after subsampling (see Fig. 8c), an overlapping occurs along the diagonal frequency components. The effect of this error upon the residual spectrum is indicated by

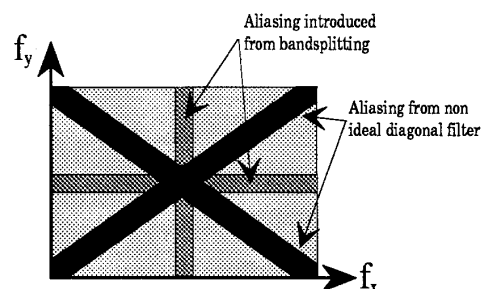


Figure 9: Frequency overlap following the subsampling of the residual signal

the dark oblique criss-cross pattern in Fig. 9, and leads to cross-talk. This is a perceptibly critical and highly visible distortion, since high horizontal frequency components become crossed-over and appear as vertical frequencies and vice versa. The worst possible example of this distortion is shown in Fig. 10, where a horizontal sweep is used as the input signal, that is a signal which comprises only x-direction frequencies between DC and half the sampling rate. The reconstructed picture shows the high vertical frequencies generated by cross-talk. The visibility of these errors is further exacerbated by the interlace, since an additional 25Hz flicker is also introduced.

Various diagonal filter designs have been investigated in an attempt to minimise cross-talk distortion, without either compromising overall picture quality or significantly increasing the order of the filter to improve the rate of roll-off. For this implementation, a high-order prefilter is desirable for the coder, such as a 31 by 31 tap response, to ensure maximum cross-talk attenuation, while a much lower filter order is used at the receiver for post-processing. Fig. 11 shows the results of using an 7 by 7 and a 15 by 15 tap linear-phase FIR diagonal filter, designed using a Kaiser window. The re-

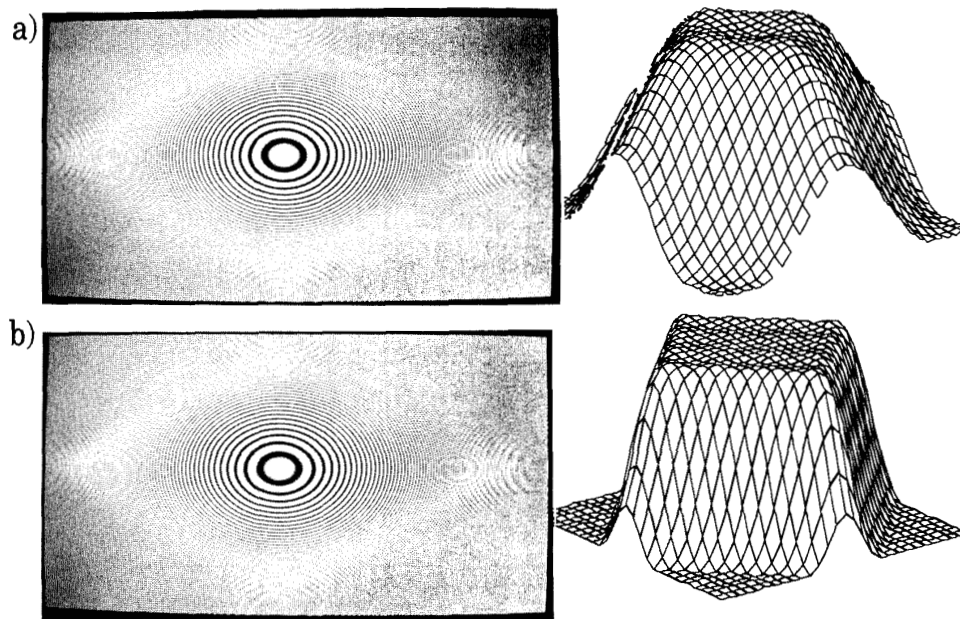


Figure 11: Reconstruction using a) 7x7 tap; b) 15x15 tap FIR diagonal post-filter

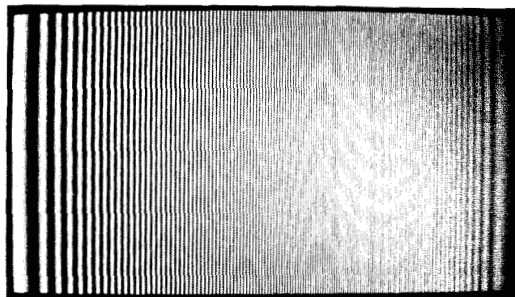


Figure 10: Horizontal/vertical frequency cross-talk

spective filter parameters and frequency responses are furnished in Fig. 12. The 31 by 31 tap FIR prefilter response is plotted in Fig. 12. The higher-order response clearly generates less overlap error because the transition bandwidth of the filter is narrower, though the processing overhead is commensurately greater.

2.4. Further data compression

As alluded in the previous section, the bandwidth of the residual component is equivalent to that of the standard resolution signal, so when amalgamating these two signals together, supplementary compression techniques are required, in order to achieve as high a data reduction ratio as possible. The merits and demerits of

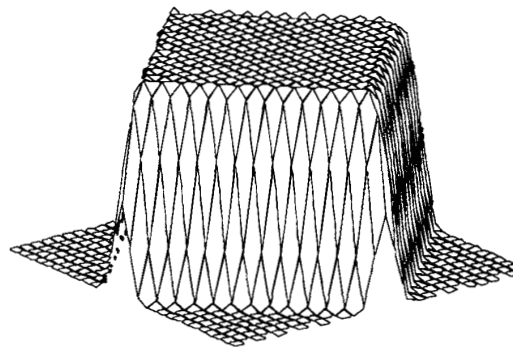


Figure 12: Frequency response of a 31x31 tap FIR diagonal prefilter

applying traditional lossless and lossy compression algorithms will now be analysed. Contemporary lossless techniques typically provide a maximum compression rate of only two, which is clearly not sufficient for this particular application. The generic family of Differential Pulse Code Modulation (DPCM) schemes is not very efficient either, because the residual component is already a differential signal. In essence therefore, the minimum compression ratio that has to be achieved is at least 30, so a more sophisticated approach is necessary. Using intrafield methods, such as the ubiquitous Discrete Cosine Transformation (DCT), which is defined in the Joint Picture Expert Group (JPEG) still-image compression standard [12], raises a number of problems. The most fundamental of these is that the quantizing tables used for the DCT coefficients, are no longer consistent with the spectral properties of the residual signal. The subsampling process illustrated in Fig. 8c, exchanges the spectral locations, so that for example, the DC level now represents the highest frequency component. This means that the DCT quantizing tables have to be modified, as they are normally optimized for the complete reverse situation, where the DC level is the average brightness and the AC coefficients represent the horizontal, vertical and diagonal frequency components. In comparison to these lossless schemes, considerably more care has to be exercised in general, when using lossy intrafield compression techniques, because both the residual component and the standard resolution signal, consist of spectral elements which are intended for alias compensation at the TV receiver. Distortions introduced by the lossy nature of a compression algorithm can very easily compromise picture quality by introducing additional aliasing artefacts. It is not always the case that such distortion is visually apparent, but the viewer's subjective impression of the picture quality must be taken into account in the course of realising any such algorithm.

Of much greater promise are the data compression techniques that are based upon interfield methods and temporal subsampling. Fig. 5a shows that the residual signal component has a maximum temporal resolution of only 12.5Hz , which affords the possibility of decimating by a factor of two. In addition, bi-directional temporal prediction, which is well known in the context of the Motion Picture Expert Group (MPEG) standard [13], provides considerable potential for reaching the requisite data compression rate. These particular techniques are currently under active investigation.

3. Future Enhancements

3.1. Colour processing

This paper has solely concentrated upon the processing of the luminance signal and the ensuing attempts at achieving high picture quality at low data rates. To date, no colour resolution enhancements have been implemented, which means that the high resolution output signal from the encoder will only possess the colour resolution of a normal PAL transmission. In the vertical direction the effect of this limitation is not too dramatic, since the human eye perceives the luminance components, which compensate somewhat for the hiatus. In the horizontal direction however, the effect it is very poor and the loss of colour resolution clearly visible. Hence, in the final implementation of the PALplus compatible encoder, a second residual signal path is derived which will contain all the necessary horizontal colour resolution information, in order to provide a balanced colour impression at the receiver.

3.2. Composite Signal Format

The other major task required in the proposed system, is the final integration phase of the digital residual component, with the standard analogue PALplus signal, without compromising compatibility. Modern digital multiplexing and modulation techniques appear to afford considerable potential to solve this particular issue and research is continuing in order to achieve the best overall format for the compatible signal.

4. Conclusions

This paper has proposed a new processing system, which affords the possibility of deriving a compact encoded signal, which facilitates HDTV transmissions that are PALplus compatible. The encoder design has been fully elucidated, together with the various constituent modules that have been implemented. The important perceptual errors of aliasing and cross-talk in the residual processing path have been highlighted and solutions presented to minimise their deleterious effects. The introduction of a motion-adaptive prefilter has also been discussed, to enable the encoder to combine the epithets of both intrafield and interfield processing in the subsampling signal path. Finally, two prospective developments, which are necessary for full compatibility were introduced, namely enhanced colour resolution and the format of the composite output signal.

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Biographies



Gunnar Schmidt (M'93) was born in Braunschweig, Germany in 1966. He received his Dipl-Ing. degree in Electronics and Communication Technology in 1990 from the Fachhochschule Braunschweig/Wolfenbuettel, Germany. Since 1990 he has been working with the video signal & picture processing group in the Department of Communication Technology at the Fachhochschule Braunschweig/Wolfenbuettel. He is currently a registered research student in the Department of Electronics and Information Technology at the University of Glamorgan, Wales, studying for his Ph.D. degree.

His main research interests are in the fields of digital signal processing, HDTV systems, video technology and digital data compression techniques.



Laurence S. Dooley (M'81-SM'92) was born in Cwmbran, Wales in 1959. He received his B.Sc., M.Sc. and Ph.D. degrees in Electrical and Electronic Engineering from the University College of Wales, Swansea in 1981, 1983 and 1987 respectively. He worked as a consultant engineer for industry, principally in the area of digital sound synthesiser design for Marine and Bridge simulator systems, before joining the Department of Electronics and Information Technology at the University of Glamorgan in 1986, where he is currently a Senior Lecturer. In 1989 he was a Visiting Scholar in the Department of Electrical Engineering at the University of Sydney, NSW, Australia.

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Prof. Dr. Wolf-Peter Buchwald was born in 1954. He studied Communication Technology at the Technical University of Braunschweig, Germany, where he received his Ph.D. degree in 1986. In 1989 he was appointed Professor in Communication Technology and Digital TV techniques at the Fachhochschule Braunschweig/Wolfenbuettel, Germany. He has provided a number of course for industry in the general area of digital video technology.

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